OPEN-FILE REPORT 2000-011

SEISMIC HAZARD EVALUATION OF THE PRADO DAM 7.5-MINUTE QUADRANGLE, ORANGE COUNTY, CALIFORNIA

2000

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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PREFACE

With the increasing public concern about the potential for destructive earthquakes in northern and southern California, the State Legislature passed the Seismic Hazards Mapping Act in 1990. The purpose of the Act is to protect the public from the effects of strong ground shaking, liquefaction, landslides or other ground failure, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act closely resemble those of the Alquist-Priolo Earthquake Fault Zoning Act (which addresses only surface fault-rupture hazards) and are outlined below:

1. **The State Geologist** is required to delineate the various "seismic hazard zones."

2. **Cities and Counties**, or other local permitting authorities, must regulate certain development "projects" within the zones. They must withhold the development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans.

3. **The State Mining and Geology Board (SMGB)** provides additional regulations, policies, and criteria to guide cities and counties in their implementation of the law. The SMGB also provides criteria for preparation of the Seismic Hazard Zone Maps (Web site http://www.consrv.ca.gov/dmg/shezp/zoneguid/) and for evaluating and mitigating seismic hazards.

4. **Sellers (and their agents)** of real property within a mapped hazard zone must disclose at the time of sale that the property lies within such a zone.

As stated above, the Act directs the State Geologist, through the Division of Mines and Geology (DMG) to delineate seismic hazard zones. Delineation of seismic hazard zones is conducted under criteria established by the Seismic Hazards Mapping Act Advisory Committee and its Working Groups and adopted by the California SMGB.

The Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Evaluation Reports, released as Open-File Reports (OFR), summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These Open-File Reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. Copies of the reports may be purchased at the Sacramento, Los Angeles, and San Francisco offices. In addition, the Sacramento office offers prepaid mail order sales for all DMG OFRs. **NOTE: The Open-File Reports are not available through BPS Reprographic Services.**

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Seismic Hazard Evaluation Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that the 1) process for zoning liquefaction hazards remain unchanged and that 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Evaluation Report summarizes the development of the hazard zone map for each area. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historic high-water-table information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Prado Dam 7.5-minute Quadrangle (scale 1:24,000).

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Prado Dam 7.5-Minute Quadrangle, Orange County, California

By
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California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Prado Dam 7.5-minute Quadrangle (scale 1:24,000). This section and Section 2 addressing earthquake-induced landslides, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure has historically been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated granular sediments within the upper 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Prado Dam Quadrangle.

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils is generally confined to areas covered by Quaternary sedimentary deposits. Such areas consist mainly of alluviated valleys, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth and thickness of liquefiable sediments, depth to ground water, rate of drainage, slope gradient, proximity to free-face conditions, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to determine the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction potential, opportunity, susceptibility, and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Orange County portion of the Prado Dam Quadrangle covers an area of about 8 square miles at the eastern end of the Puente Hills. The map includes parts of the cities of Anaheim and Yorba Linda, as well as unincorporated Orange County land. The Santa Ana River and minor tributary creeks drain the southwestern portion of the quadrangle. Elevations range from about 300 feet along the Santa Ana River, near the southwestern corner of the quadrangle, to 1,781 feet at San Juan Hill in the Puente Hills along the Orange County-San Bernardino County boundary line in the southwestern quarter of the quadrangle.

The incised meanders of the Santa Ana River and the associated elevated stream terraces are the dominant geomorphic features in the southwestern corner of the quadrangle. The Puente Hills, which lie at the eastern margin of the Los Angeles Basin, dominate the upland terrain and form a bold backdrop to the Santa Ana River canyon. Elevations of hilltops range from about 400 feet to 1,781 feet in the hills. The mid-slope section has been sculpted by erosion into a complex system of generally south-draining canyons and tributary gullies.

Near the southern part of the quadrangle, the Riverside Freeway (State Highway 91), a major artery that connects the Los Angeles area with Riverside County, follows the southern bank of the Santa Ana River. Tracks of the Atchison, Topeka, and Santa Fe Railroad follow the northern bank of the Santa Ana River.

Commercial development is dense in the Santa Ana River Canyon. Residential development over the past twenty years has taken place along the lower slopes and ridgetops of the bordering uplands. Parks and “greenbelts” highlight the trace of the Whittier fault zone through the residential areas. Most of the modern projects in the upland areas required substantial grading and drainage modification prior to construction.

GEOLOGIC CONDITIONS

Surface Geology

The geologic map for the Prado Dam Quadrangle was digitized by the Southern California Areal Mapping Project [SCAMP](1995) from DMG 1:12,000-scale mapping by Miller (1984). The study area geology is also presented in a 1:48,000-scale regional geologic compilation by Morton and Miller (1981) and at 1:100,000 scale by Greenwood and Morton (1990). Quaternary unit designations were compiled from Miller (1984) by the Southern California Areal Mapping Project (1995) and received “spot field review” during the course of this investigation. The Quaternary geologic map of the Prado Dam Quadrangle is reproduced as Plate 1.1.

Quaternary deposits of older alluvium flank the lower slopes of the Puente Hills and lie within the drainage course of the Santa Ana River. The deposits along the Santa Ana River and adjacent minor streams include late Pleistocene (?) to Holocene stream and terrace deposits (Qt4, Qt3, Qt2, Qt1, Qt, Qvofsa, Qal, Qsw). These deposits consist of unconsolidated to poorly consolidated mixtures of sand, silt, and gravel. The only units mapped in this quadrangle as artificial fill (af) are earth-filled embankment dams and highway-related engineered fills.

Characteristics of geologic units recorded on the geologic map and in borehole logs are described below. The descriptions are necessarily generalized but give the most commonly encountered characteristics of the units (see Table 1.1).

Subsurface Geology and Geotechnical Characteristics

Information on subsurface properties was obtained from more than 23 borehole logs in the study area. Subsurface data used for this study include water well logs from the California Department of Water Resources and the Orange County Water District and geotechnical logs from larger geotechnical firms.

Locations and geotechnical data from borehole logs were entered into DMG's Geographic Information System (GIS). Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2. Construction of cross sections using data reported on the borehole logs enabled staff to relate soil engineering properties to various depositional units, to correlate soil types from one borehole to another, and to extrapolate geotechnical data into outlying areas containing similar soils. These deposits are discussed below.

Older, elevated terrace deposits (Qt4, Qt3, Qt2, Qt1, Qt)

Late Pleistocene (?) elevated terrace deposits in the Prado Dam Quadrangle occur on the southern slopes of the Puente Hills. The terrace gravels are isolated on slopes or found at the base of slopes where ground water is deep, so no extensive effort was made to collect subsurface data.

Older fan deposits (Qvofsa)

Older, late Pleistocene (?), fan deposits were mapped by Miller (1984) on the north side of the Santa Ana River but were inadvertently left unlabeled and subsequently labeled by SCAMP (1995). These deposits are dissected by active drainage courses and typically consist of dense to very dense sand and gravel with interbedded sand and silty sand. This unit is likely a stratigraphic equivalent of Qt3.

Slope Wash deposits (Qsw)

Slope wash deposits in the Prado Dam Quadrangle occur along the base of slopes, adjacent to drainages and at the heads of drainages. They generally consist of soft, wet, sand to silty-sand deposits in drainages of the Puente Hills.

Active wash deposits (Qal)

Miller (1984) identified active wash deposits within the active drainages of the Santa Ana River and adjacent drainages. They generally consist of wet, loose, silty-sands and gravelly sands in the Santa Ana River drainage and wet, soft silty-sands in the adjacent drainages of the Puente Hills.

Geologic Map Unit	Material Type	Consistency	Age
Qal, active wash deposits	Silty-sand, and gravelly-sand	Loose	Historic time
Qsw, slope wash deposits	sand, silty-sand	Soft	Holocene
Qvofsa, older fan deposits	sand & gravel, sand, silty-sand	dense-very dense	Late Pleistocene (?)
Qt4, Qt3, Qt2, Qt2, Qt1, Qt older elevated terrace deposits	sand & gravel, silty-sand	dense-very dense	Late Pleistocene (?)

Table 1.1. Quaternary stratigraphic nomenclature used in the Prado Dam Quadrangle.

GROUND-WATER CONDITIONS

Liquefaction hazard mapping focuses on areas historically characterized by ground-water depths of 40 feet or less. Accordingly, ground-water conditions were investigated in the Prado Dam Quadrangle to evaluate the depth to saturated sediments. Saturated conditions reduce the normal effective stress acting on loose, near-surface sandy deposits, thereby increasing the likelihood of liquefaction (Youd, 1973). Ground-water depth data were obtained from geotechnical boreholes, water-well logs, and environmental monitoring wells. The evaluation was based on first-encountered water levels encountered in the boreholes and selected water wells. The depths to first-encountered water, free of piezometric influences, were plotted onto a map of the project area showing depths to historically shallowest ground water (Plate 1.2). Such a map differs from most ground-water maps, which show the actual water table at a particular time, in that this map depicts a hypothetical ground-water table. This map was digitized and used for the liquefaction analysis.

The geotechnical boreholes indicate perennial high ground water in the Santa Ana River drainage and in the upper portions of the tributary drainages in the Puente Hills. Sediments in these drainages are, accordingly, assumed to be saturated during periods of high precipitation. The Orange County Water District maintains subsurface inflow in the Santa Ana River Canyon, in accordance with ground-water basin-management practices.

PART II

EVALUATING LIQUEFACTION POTENTIAL

Liquefaction occurs in water-saturated sediments during moderate to great earthquakes. Liquefied sediments are characterized by a loss of strength and may fail, causing damage to buildings, bridges, and other such structures. A number of methods for mapping liquefaction hazard have been proposed; Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of susceptibility units, and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce liquefaction potential. Liquefaction susceptibility is a function of the capacity of sediments to resist liquefaction and liquefaction opportunity is a function of the seismic ground shaking intensity. The application of the Seed Simplified Procedure (Seed and Idriss, 1971) for evaluating liquefaction potential allows a quantitative characterization of susceptibility of geologic units. Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for mapping liquefaction hazards in the Los Angeles region. The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985), combining geotechnical data analyses, and geologic and hydrologic mapping, but follows criteria adopted by the California State Mining and Geology Board (in press).

LIQUEFACTION OPPORTUNITY

According to the criteria adopted by the California State Mining and Geology Board (in press), liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period. The earthquake magnitude is the magnitude that contributes most to the acceleration.

For the Prado Dam Quadrangle, a peak acceleration of 0.53 to 0.60 g resulting from an earthquake of magnitude 6.8 was used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996) and Cramer and Petersen (1996), respectively. See the ground motion portion (Section 3) of this report for further details.

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of soils to loss of strength when subjected to ground shaking. Primarily, physical properties and conditions of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance. These properties and conditions are correlated with geologic age and environment of deposition. With increasing age of a deposit, relative density may increase through cementation of the particles or the increase in thickness of the overburden sediments. Grain size characteristics of a soil also influence susceptibility to liquefaction. Sands are more susceptible than silts or gravels, although silts of low plasticity are treated as liquefiable in this investigation. Cohesive soils are generally not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in lower liquefaction susceptibility generally result in higher penetration resistances to the soil sampler. Different blow count corrections are used for silty sand and nonplastic silt than for clean sand (Seed and others, 1985). Therefore, blow count or cone penetrometer values are a useful indicator of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (more likely to liquefy). Soils that lack resistance (susceptible soils) are typically saturated, loose sandy sediments. Soils resistant to liquefaction include all soil types that are dry or sufficiently dense.

DMG’s map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil-property and soil-condition factors such as type, age, texture, color, and consistency, along with historic depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, findings can be related to the map units. DMG’s qualitative susceptible soil inventory is summarized on Table 1.2.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and others, 1985; National Research Council, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (SPT) results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site related structures. For a regional assessment DMG normally has a range of FS that results from the liquefaction analyses. The DMG liquefaction analysis program calculates an FS at each sample that has blow counts. The lowest FS in each borehole is used for that location. These FS vary in reliability according to the quality of the geotechnical data. These FS as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil are evaluated in order to construct liquefaction potential maps, which then directly translate to Zones of Required Investigation**.**

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Susceptible to Liquefaction?*
Qal	Sandy, silty sand	active stream channels	Loose	Yes
Qsw	sand, silty-sand	Slope wash	Soft	Yes
Qvofsa	Sand and gravel, sand, and silty-sand	Older fan deposits	Dense to very dense	Not likely
Qt4, Qt3, Qt2, Qt1, Qt	Sand and gravel, and silty sand	Older, elevated terrace deposits	Dense to very dense	Not likely

* When saturated.

Table 1.2. General geotechnical characteristics and liquefaction susceptibility of Quaternary sedimentary units.

Of the 23 geotechnical borehole logs used in this study (Plate 1.2), 9 include blow-count data from SPT's or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 1/2-inch inside diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (soil density, moisture content, sieve analysis, etc) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values or using average test values of similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

The areas underlain by late Quaternary geologic units were included in liquefaction zones using the criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (in press). Under those criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historic earthquakes.

2. All areas of uncompacted fills containing liquefaction susceptible material that are saturated, nearly saturated, or may be expected to become saturated.

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable.

4. Areas where existing geotechnical data are insufficient.

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria for liquefaction zoning in the Prado Dam Quadrangle is summarized below.

Areas of Past Liquefaction

In the Prado Dam Quadrangle, no areas of documented historic liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported.

Artificial Fills

In the Prado Dam Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for river levees and elevated freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

Areas with Sufficient Existing Geotechnical Data

The study area does not contain sufficient areal distribution or density of boreholes, nor is the quality of data collected in this investigation from the existing boreholes sufficient to adequately evaluate the liquefaction susceptibility.

Areas with Insufficient Existing Geotechnical Data

Geologic conditions were adequately identified and characterized by representative surface geologic mapping, at a scale which is appropriate for this regional hazard analysis, and by logs from available subsurface boreholes and wells. The areas were placed within Zones of Required Investigations because such soils generally reflect conditions named in the SMGB criteria items 4a-c.

ACKNOWLEDGMENTS

The author would like to thank Leighton and Associates, California Department of Water Resources, and the Orange County Environmental Management Agency—Construction Division, and the Orange County Water District for their cooperation and access to subsurface data which has made this study possible.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Prado Dam 7.5-Minute Quadrangle, Orange County, California

By
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California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Orange County portion of the Prado Dam 7.5-minute Quadrangle (scale 1:24,000). This section and Section 1 addressing liquefaction, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/.

BACKGROUND

Landslides triggered by earthquakes have historically been a major cause of earthquake damage. Landslides triggered by the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes were responsible for destroying or damaging numerous homes and other structures, blocking major transportation corridors, and damaging various types of lifeline infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, in loose soils, and on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, most notably in hilly areas already developed or currently undergoing development. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region, which includes the Prado Dam Quadrangle.

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered primarily from a variety of outside sources; thus the quality of the data is variable. Although the selection of data used in this evaluation was rigorous, the State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Earthquake-generated ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. No attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Prado Dam Quadrangle, for more information on the delineation of liquefaction zones.

Information developed in the study is presented in two parts: physiographic and geologic conditions in PART I, and ground shaking opportunity, landslide hazard potential and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Orange County portion of the Prado Dam Quadrangle encompasses approximately 8 square miles in the southwestern corner of the quadrangle. This area covers the eastern third of the City of Yorba Linda, a small segment of the City of Anaheim (along the southwestern side of Horseshoe Bend), and some unincorporated Orange County land. Most of the of the quadrangle lies within Riverside and San Bernardino counties where evaluation for zoning has not been done.

The Prado Dam Quadrangle lies at the northwestern end of the Santa Ana Mountains in the Peninsular Ranges geomorphic province. Much of the quadrangle, including the entire Orange County portion, is in the Chino Hills, where relief is fairly high. Elevations range from about 300 feet along the Santa Ana River to 1781 feet at San Juan Hill, which is on the county line. The hills and ridges are cut by deep drainages, such as Brush and Blue Mud canyons. The Santa Ana River, especially the Horseshoe Bend, meanders along the southern boundary of the quadrangle. The Whittier Fault zone, which strikes northwesterly, crosses through the center of the study area.

No highways run through the study area, though the Burlington Northern - Santa Fe Railroad runs along the northern side of the Santa Ana River channel. Roughly half of the study area, primarily the southern portion, has been built over by housing developments with interconnecting roads. Mass grading, including the filling of canyons and cutting of ridgetops, for some of the large housing tracts has modified the natural topography. The northern half of the study area remains as open land.

GEOLOGIC CONDITIONS

Surface and Bedrock Geology

The geologic map for the Prado Dam Quadrangle was digitized by the Southern California Areal Mapping Project [SCAMP](1995) from DMG 1:12,000-scale mapping by Miller (1984). The study area geology is also presented in a 1:48,000-scale regional geologic compilation by Morton and Miller (1981) and at 1:100,000 scale by Greenwood and Morton (1990). The map was modified for this project to reflect additional field observations and to allow the landslides to be addressed separately. The following descriptions of the geologic units are based on Miller (1984).

The oldest geologic unit mapped in the study area is the undifferentiated Vaqueros and Sespe Formation (Tvs), which is late Eocene to early Miocene. This unit locally consists of marine carbonaceous siltstone interbedded with non-marine sandstone and is exposed in small outcrops south of the Whittier Fault. Tvs is conformably overlain by the middle Miocene Topanga Formation (Tt), which is present in the same general area but with much greater exposure. The Topanga Formation consists of thickly bedded sandstone with interbeds of conglomerate and siltstone. These two units generally maintain fairly stable slopes.

The late Miocene Puente Formation, which overlies the Topanga Formation, consists of four members. The oldest is the La Vida Member (Tpl), which is characterized by siltstone with limey concretions, micaceous siltstone and interbedded sandstone. The Soquel Member (Tps) consists of thickly bedded sandstone with interbedded siltstone. The Yorba Member (Tpy), which is the most widely exposed of the members of the mapped units in the study area, locally resembles the La Vida with diatomaceous siltstone. The youngest subunit of the Puente Formation is the Sycamore Canyon Member (Tpsc). It consists of conglomerate, conglomeratic sandstone, and thin to massive sandstone or siltstone. The Puente Formation, with the exception of Sycamore Canyon Member, tends to have poor slope stability characteristics.

The oldest Quaternary unit mapped in the Orange County portion of the Prado Dam Quadrangle consists of late Pleistocene to Holocene stream terrace deposits (Qt). These deposits, along with Quaternary alluvium (Qal), are present along and adjacent to the Santa Ana River canyon. Slopewash (Qsw) is present in upstream drainage channels and on lower portions of hill slopes. Artificial fill (af) is mapped along the south end of the study area primarily associated with the railroad and other small areas. No attempt has been made to map the fill placed for housing tracts. The mapped Pleistocene to Holocene landslides (Qls) are most abundant north of the Whittier Fault, where the steep terrain and extensive exposures of the Puente Formation are characteristic. A more detailed discussion of the Quaternary deposits in the Prado Dam Quadrangle can be found in Section 1.

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, they first must be ranked based on their overall shear strength. Generally, the primary source for soil and rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear strength data for the geologic units in the Prado Dam Quadrangle were obtained from the files of Leighton and Associates and the City of Yorba Linda (see Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

Shear strength data gathered from the above sources were compiled for each mapped geologic unit and subdivided for fine-grained and coarse-grained lithologies when appropriate. Geologic units were grouped on the basis of average angle of internal friction (average f) and lithologic character. Shear tests from adjacent quadrangles were used to augment data for geologic formations that had little or no shear test information. For the Prado Dam Quadrangle, roughly two-thirds of the shear test values used to calculate rock strength were borrowed from adjacent quadrangles.

To subdivide mapped geologic formations that have both fine-grained and coarse-grained lithologies, we assumed that where stratigraphic bedding dips into a slope (favorable bedding) the coarse-grained material strength dominates, and where bedding dips out of a slope (adverse bedding) the fine-grained material strength dominates. We then used structural information from the geologic map (see “Structural Geology”) and terrain data in the form of slope gradient and aspect, to identify areas with a high potential for containing adverse bedding conditions. These areas, located on the map, were then used to modify the geologic material-strength map to reflect the anticipated lower shear strength for the fine-grained materials.

The results of the grouping of geologic materials for the Prado Dam Quadrangle are in Tables 2.1 and 2.2.

	Formation Name	Number of Tests	Mean/Median Phi (deg)	Group Mean/Median Phi (deg)	Group Mean/Median Cohesion (psf)	No Data: Similar Lithology	Phi Used In Stability Analyses
GROUP 1	Qsw	5	**30.0/32.0**				
	Qal	20	**33.8/33.0**				
	Tpsc	5	**34.6/35.0**				
	Tpy	5	**32.4/32.0**	33.6/33.0	393/250		**33.6**
	Tpl	1	**35.0/35.0**				
	Tt	14	**31.7/33.5**				
	Tvs	16	**36.2/34.0**				
GROUP 2	af	12	**30.3/29.0**				
	Qt	28	**29.3/29.0**	29.6/29.0	506/283	Qsw/Qt	**29.6**
	Tps - fbc	2	**29.5/29.0**				
GROUP 3	Tps - abc	7	**23.4/22.0**	23.4/22.0	250/200		**22.0**
GROUP 4	Qls	7	**17.7/15.0**	17.7/15.0	554/550		**15.0**

PRADO DAM QUADRANGLE SHEAR STRENGTH GROUPS

abc = adverse bedding conditions
fbc = favorable bedding conditions

Table 2.1. Summary of the Shear Strength Statistics for the Prado Dam Quadrangle.

SHEAR STRENGTH GROUPS FOR PRADO DAM QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4
Qsw, Qal, Tpsc, Tpsc-c, Tpy, Tpy-s, Tpl, Tt, Tvs	af Qt Qsw/Qt Tps (fbc)	Tps (abc)	Qls

Table 2.2. Summary of the Shear Strength Groups for the Prado Dam Quadrangle.

Structural Geology

Accompanying the digital geologic map from the SCAMP program were digital files of associated geologic structural data, including bedding and foliation attitudes (strike and dip) and fold axes. We used this structural geologic information to categorize areas of common stratigraphic dip direction and magnitude, similar to the method presented by Brabb (1983). The dip direction category was compared to the slope aspect (direction) category and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category and the bedding dip was greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area. This information was then used to subdivide mapped geologic units into areas where fine-grained and coarse-grained strengths would be used.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete picture of the previous occurrence of landsliding. An inventory of existing landslides in the Prado Dam Quadrangle was prepared by combining an analysis of aerial photographs, an interpretation of landforms from topographic maps, and a review of the previous geologic mapping (Miller, 1984). Three sets of aerial photographs taken from 1952 to 1994 collectively covered the project area and are listed under References. The completed hand-drawn landslide map was digitized and information on confidence of interpretation (definite, probable, or questionable) and other properties, such as activity, thickness, and associated geologic unit(s) was compiled in a database. A version of this landslide inventory is included with Plate 2.1.

PART II

EARTHQUAKE-INDUCED LANDSLIDE GROUND SHAKING OPPORTUNITY

Design Strong-Motion Record

The Newmark analysis used in delineating the earthquake-induced landslide zones requires the selection of a design earthquake strong-motion record. For the Prado Dam Quadrangle, the selection was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996; Cramer and Petersen, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8
Modal Distance:	2.6 to 6.6 km
PGA:	0.49 to 0.58 g

The strong-motion record selected was the USC Station #14 record (Trifunac and others, 1994) from the 1994 6.7-Mw Northridge earthquake. This record had a source to recording site distance of 8.5 km and a PGA of 0.59 g. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

To develop a relationship between the yield acceleration (a_y; defined as the horizontal ground acceleration required to cause the factor of safety to equal 1.0) and Newmark displacements, the design strong-motion record was integrated twice for a given a_y to find the corresponding displacement, and the process repeated for a range of a_y (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for any combination of geologic material strength and slope angle, as represented by the yield acceleration. We used displacements of 30, 15 and 5 cm as criteria for rating levels of earthquake shaking damage on the basis of the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.129 and 0.232g. These yield acceleration values were then used as earthquake-induced landslide susceptibility criteria in the stability analyses.

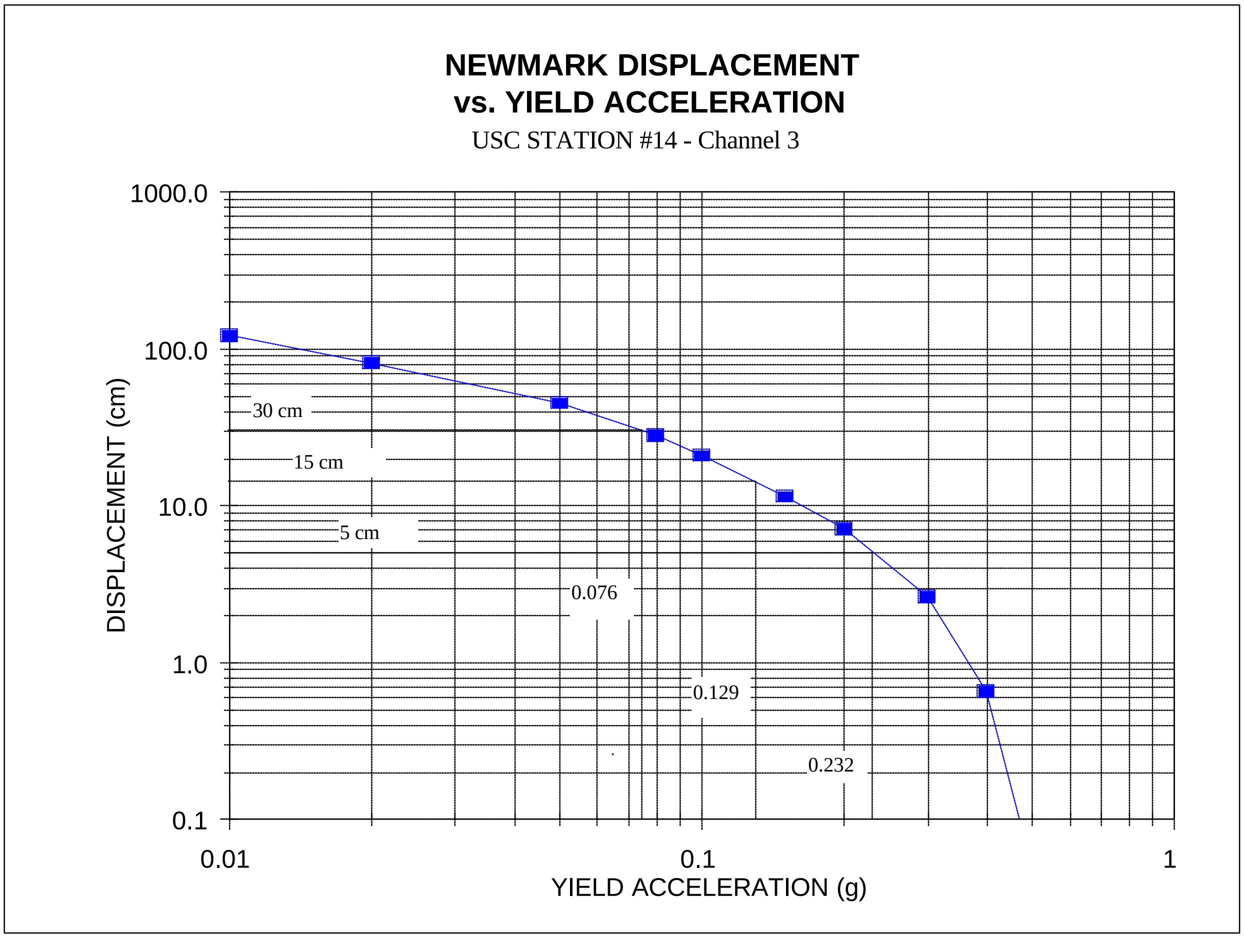

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. To calculate slope gradient for the terrain within the Prado Dam Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1995). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy. Surrounding quadrangle DEMs were merged with the Prado Dam DEM to avoid the loss of data at the quadrangle edges when the slope calculations were performed. A peak and pit smoothing process was then performed to remove errors in the elevation points.

Areas that have undergone large-scale grading as a part of residential development in the hilly portions of the Prado Dam Quadrangle were updated to reflect the new topography. Using 1:40,000-scale NAPP photography taken in 1994 and 1995, photogrammetric DEMs covering the graded areas were prepared by the U.S. Bureau of Reclamation with ground control obtained by DMG. The photogrammetric DEMs were then merged into the USGS DEM, replacing the areas of out-dated elevation data.

A slope-gradient map was made from the combined DEMs using a third-order, finite difference, center-weighted algorithm (Horn, 1981). This map was used in conjunction with the geologic strength map in preparation of the earthquake-induced landslide hazard potential map.

Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure, α is the same as the slope angle.

The yield acceleration calculated by Newmark's equations represents the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. The acceleration values were compared with the ground shaking opportunity, defined by Figure 2.1, to determine the earthquake-induced landslide hazard potential. Based on the criteria described in Figure 2.1 above, if the calculated yield acceleration was less than 0.076g expected displacements could be greater than 30 cm, and a HIGH (H on Table 2.3) hazard potential was assigned. Likewise, if the calculated a_y fell between .0.076g and 0.129g a MODERATE (M on Table 2.3) hazard potential was assigned, between values 0.129 and 0.232g a LOW (L on Table 2.3) potential was assigned, and if a_y were greater than value or 0.232g a VERY LOW (VL on Table 2.3) potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

PRADO DAM QUADRANGLE HAZARD POTENTIAL MATRIX										
		SLOPE CATEGORY								
		I	II	III	IV	V	VI	VII	VIII	
Strength Group	Mean Phi	0 – 13	14 - 16	17 - 26	27 - 31	32 – 40	41 - 49	50 - 56	> 56	(percent)
		0 - 7	8 - 9	10 - 14	15 - 17	18 – 22	23 - 26	27 - 29	> 29	(degrees)
1	33.6	VL	VL	VL	VL	VL	L	M	H	
2	29.6	VL	VL	VL	VL	L	M	H	H	
3	22.0	VL	VL	L	M	H	H	H	H	
4	15.0	L	M	H	H	H	H	H	H	

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Prado Dam Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone.

EARTHQUAKE-INDUCED LANDSLIDE ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (1996). Under those criteria, earthquake-induced landslide zones are areas meeting one or both of the following:

1. Areas identified as having experienced landslide movement in the past (including all mappable landslide deposits and source areas) and, where possible, areas known to have experienced earthquake-induced landsliding during historic earthquakes.

2. Areas where geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

Existing Landslides

Studies of the types of landslides caused by earthquakes (Keefer, 1984) show that re-activation of the whole mass of deep-seated landslide deposits is rare. However, it has been observed that the steep scarps and toe areas of existing landslides, which formed as a result of previous landslide movement, are particularly susceptible to earthquake-induced slope failure. In addition, because they have been disrupted during landslide movement, landslide deposits are inferred to be weaker than coherent, undisturbed, adjacent source rocks. Finally, we felt that a long duration, San Andreas fault-type earthquake could be capable of initiating renewed movement in existing deep-seated landslide deposits. Therefore, all existing landslides identified in the inventory with a definite or probable confidence of interpretation were included in the hazard zone.

Geologic and Geotechnical Analysis

On the basis of a DMG pilot study (McCrink and Real, 1996), the earthquake-induced landslide zone includes all areas determined to lie within the High, Moderate and Low levels of hazard potential. Therefore, as shown in Table 2.3, geologic strength group 4 is always included in the zone (mapped landslides); strength group 3 above 16% slope; strength group 2 above 31%; and strength group 1, the strongest rock types, were zoned for slope gradients above 40%. This results in roughly 45% of the land in the mapped portion of the quadrangle lying within the hazard zone.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. The personnel at Leighton and Associates and the Engineering Department for the City of Yorba Linda provided access to their files for shear strength data. George Knight and Monte Lorenz of the U.S. Bureau of Reclamation supplied topographic data for areas of mass grading in the quadrangle. Russ Miller, Siang Tan, and Doug Morton (USGS) did much of the detailed geologic mapping in this area. Russ Miller and Richard Greenwood of DMG provided invaluable field insights on the regional geology, structure, and identification of rock formations. Also at DMG, Scott Shepherd, Teri McGuire and Bob Moskovitz provided Geographic Information System operations support. Barbara Wanish designed and plotted the graphic displays associated with the hazard zone map and this report. Ellen Sander provided entry of geotechnical data into the database.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Leighton and Associates	**15**
City of Yorba Linda, Engineering Department	**28**
Total number of shear tests from Prado Dam Quadrangle	**43**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Prado Dam 7.5-Minute Quadrangle, Orange County, California

By

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California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included, are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5- minute quadrangle and portions of the adjacent eight quadrangles.

They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the “Simple Prescribed Parameter Value” method (SPPV) described in the site investigation guidelines (California State Mining and Geology Board, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2, addressing liquefaction and earthquake-induced landslide hazards, constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG’s Internet homepage:
http://www.consrv.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the seismogenic sources as published in the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

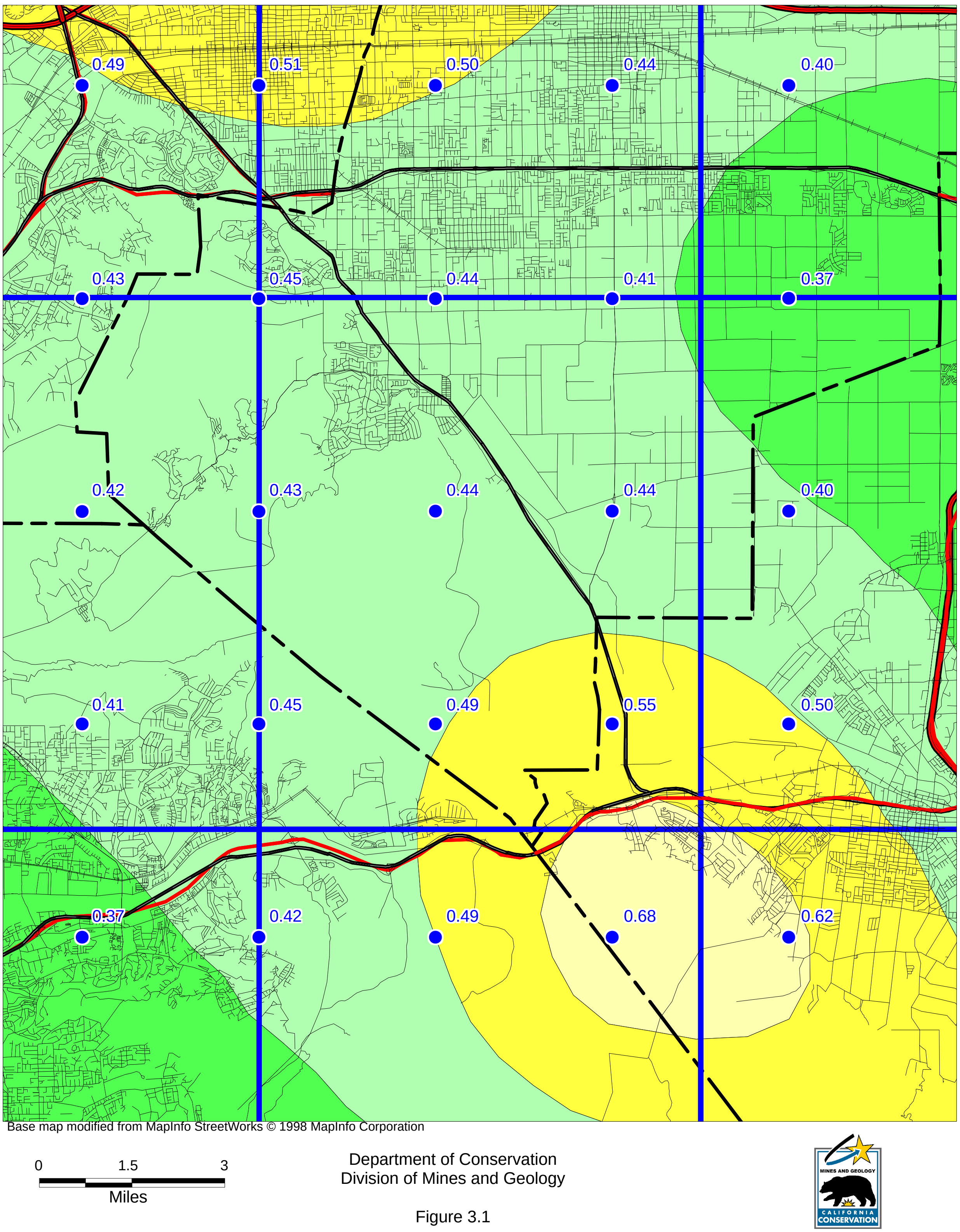
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

PRADO DAM 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Department of Conservation
Division of Mines and Geology

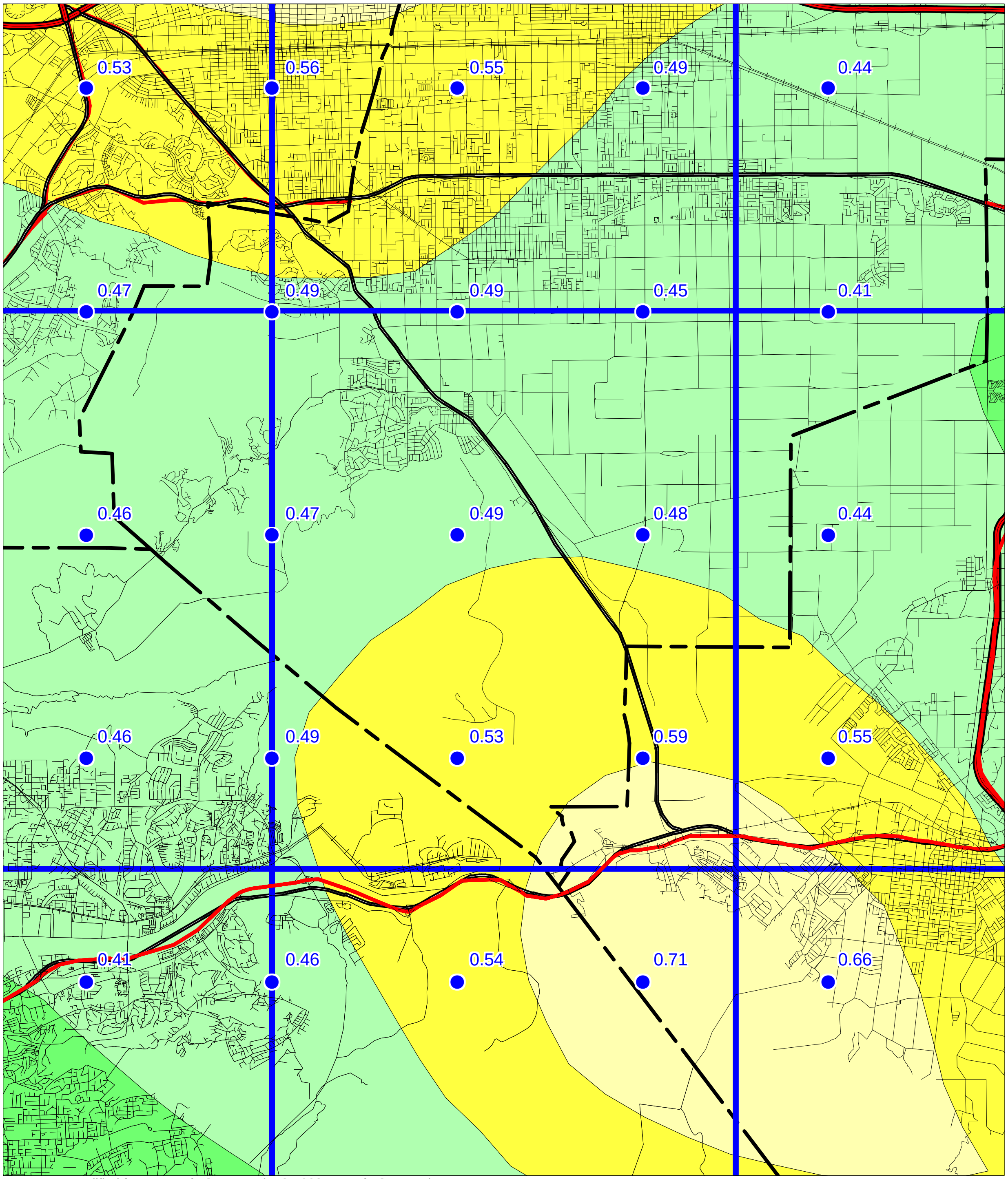
Figure 3.1

PRADO DAM 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

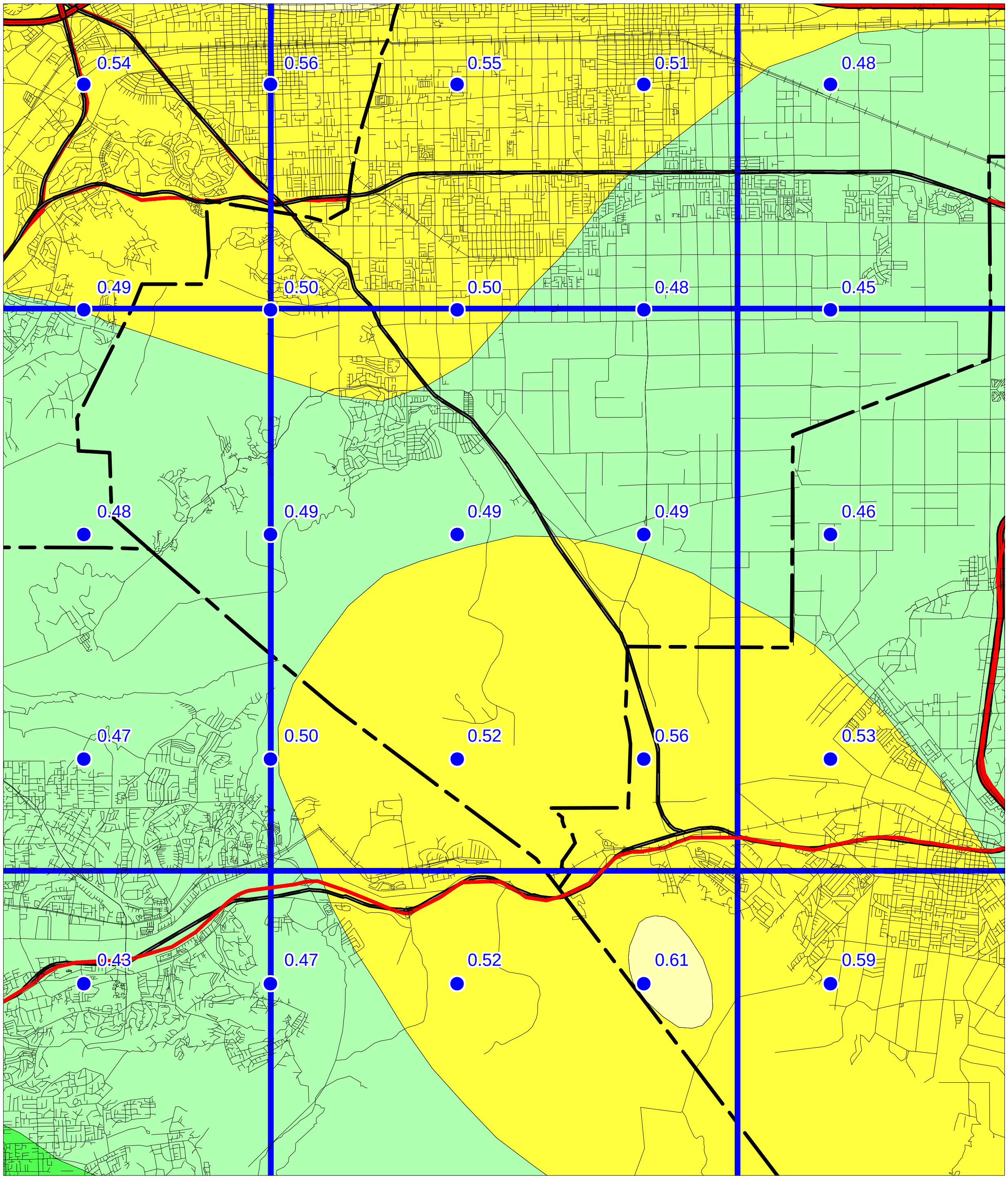
Figure 3.2

PRADO DAM 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works © 1998 MapInfo Corporation

0 1.5 3

Miles

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Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

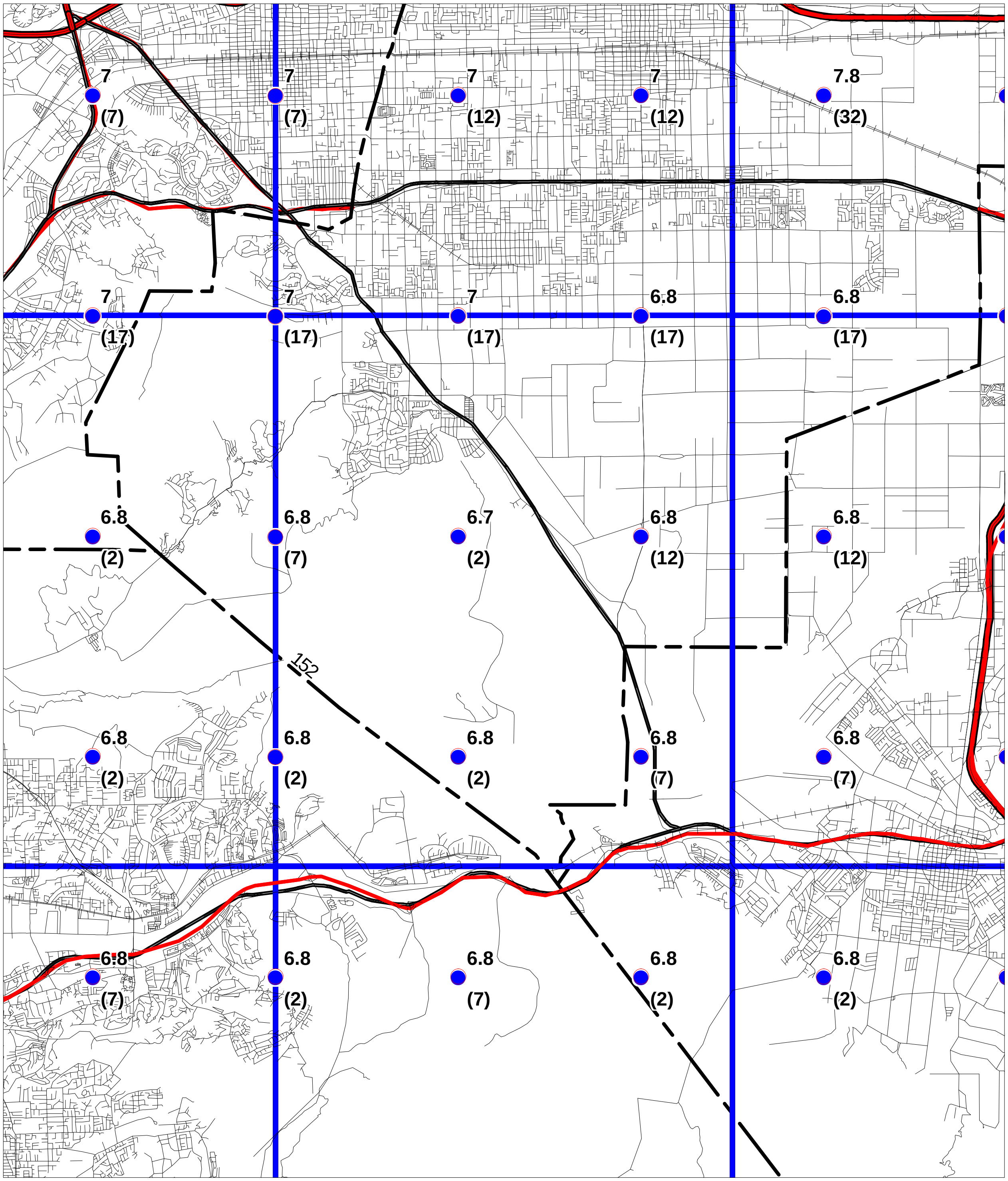
1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation

PRADO DAM 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

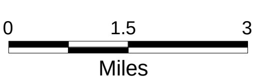


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Figure 3.4

of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not previously been recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (California State Mining and Geology Board, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

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Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 1.1 Quaternary Geologic Map of the Prado Dam Quadrangle.
See Geologic Conditions section in report for descriptions of the units.

ONE MILE
SCALE

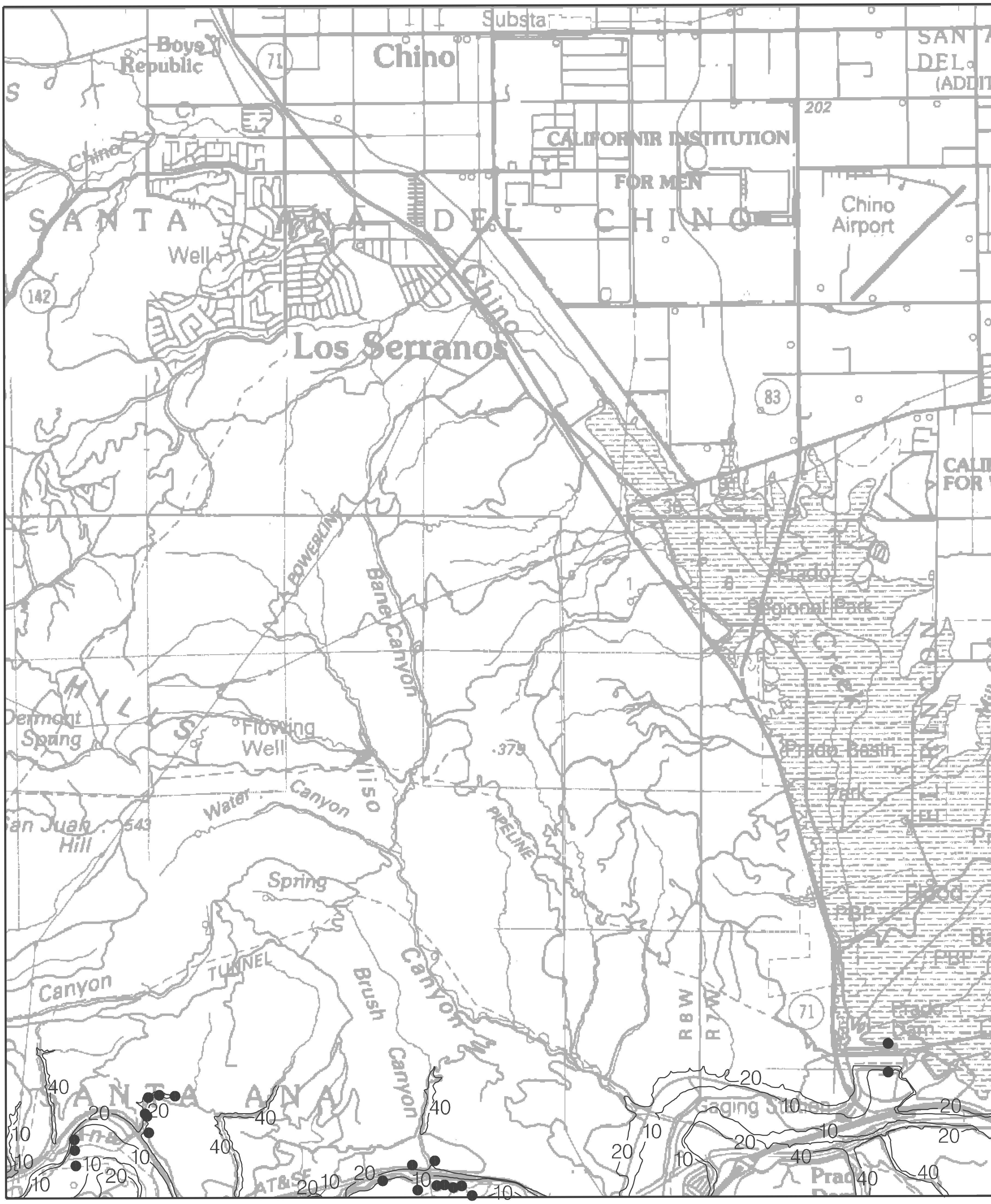


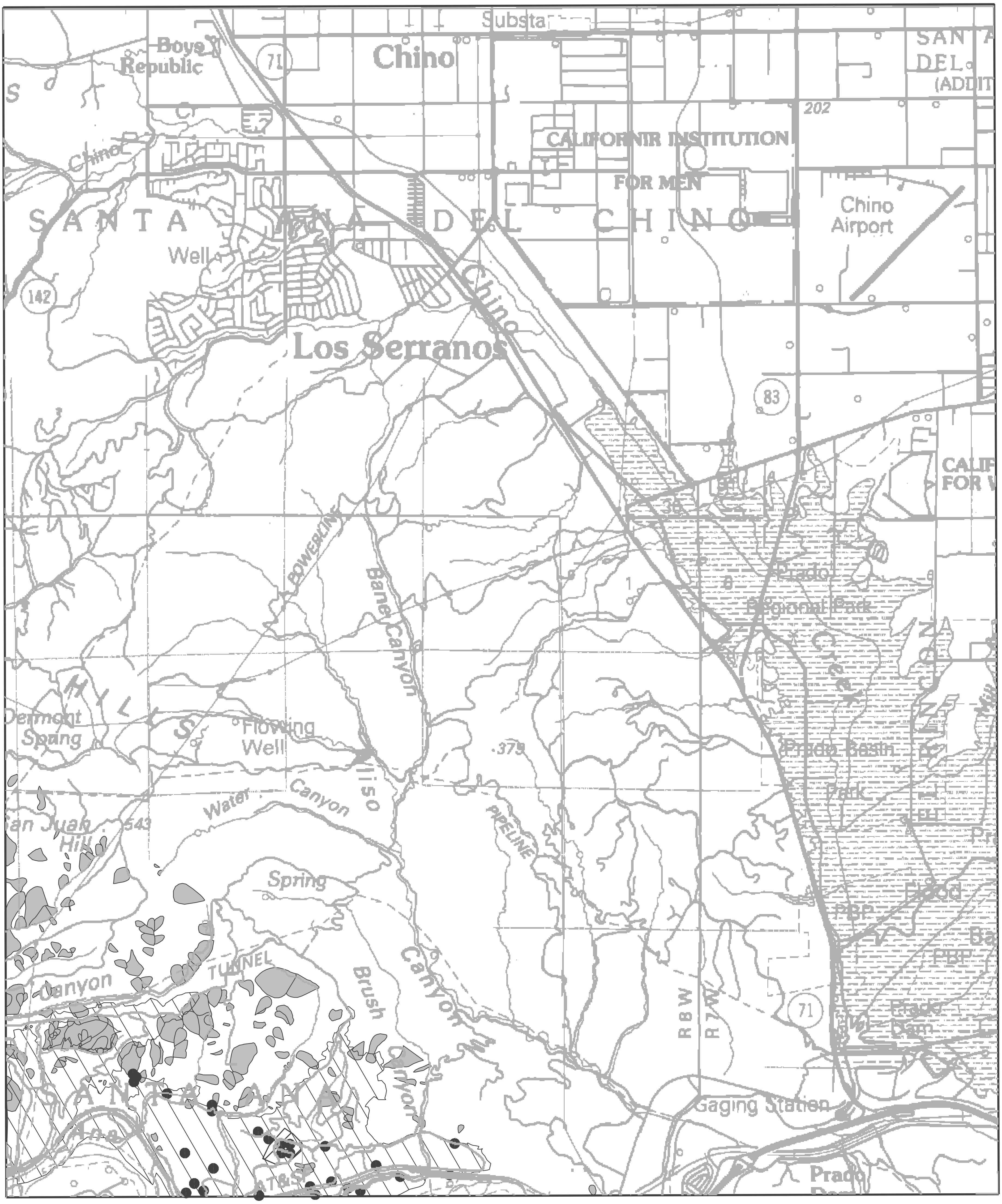
Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Prado Dam Quadrangle.

● Borehole Site

30 Depth to ground water in feet

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 2.1 Landslide inventory, Shear Test Sample Locations, and Areas of Significant Grading, Prado Dam Quadrangle.

shear test sample location
landslide
areas of significant grading
tract report with multiple borings

ONE MILE
SCALE